

Patterns and driving forces of cropland changes in the Three Gorges Area, China

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Received: 8 March 2011 / Accepted: 10 February 2012 / Published online: 28 February 2012
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Abstract Human activities, especially the launch of massive projects such as the Three Gorge Project (TGP) for the constructing the world's largest dam, the Chinese Western Region Development Project, and the Ecological Protection Projects designed to protect the natural vegetation, greatly changed the landscape pattern in the Three Gorges reservoir area (TGRA) in recent decades. In this study, remote sensing was employed to monitor pattern dynamic of the cropland, cropland quality, and cropland cultivation intensity in TGRA during the implementation period of TGP, and then the driving forces of cropland change were discussed. The results showed that the cropland area decreased by 4%, with an average annual reduction of 3,977 hectares. Of the decrease, the high-yield cropland accounted for 61%; this led to a decline in the quality of the entire cropland. Along with the decrease in cultivation intensity, the multiple cropping indexes reduced by 7% from 2003 to 2009. Urban expansion topped the list of driving forces contributing to the decline, which contributed 45% of the decline. Submergence caused by rise of water level is another sponsor to cropland reduction. Contribution of submergence to the cropland decrease was up to 16%. Besides, the ecological rehabilitation project and development of orchard industry also contributed to the decline. In 2007, the cropland with slope gradient larger than 25°, which should be returned to forests or pastures according to the land policy, still accounted for 20%.

Keywords Cropland · Three Gorge reservoir area · Reservoir submergence · Resettlement · Remote sensing

Introduction

Cropland is a fundamental and strategic resource for food security in China which has a large population (Brown 1995). However, along with the rapid growth of population and economic development, much of the cultivated land has been occupied by construction (Turner 1989; Fearnside 2001). With long-standing agricultural civilization, cropland expansion has been an important way for solving food shortage in ancient China under the pressure of enormous population (Perkins 1984), but industrialization, marketization, and globalization have combined to bring about rapid economic growth in contemporary China (Zhou and Ma 2000; Pannell 2002; Xie et al. 2005). Industrialization and urbanization have occupied a large amount of high quality cropland and balance the trend of cropland extension. The increasing conflict of cropland resource scarcity and growing population becomes an obstacle for socio-economic development. China's agricultural industry faces a scarcity of land and urgent food security (Zhang et al. 2007; Liu et al. 2005).

A better understanding of the driving forces of land cover change and how they interact is needed to improve land use theory (National Research Council 2001). This understanding will provide a way to specify the driven forces that most likely result in significant land changes or are relatively unimportant. Human activities have become the dominant force reshaping the surface of the earth (Napton et al. 2010). Cropland abandonment occurs when the agricultural system is affected by external drivers or because of its own dynamics toward extensification or intensification,

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which is usually driven by economic conditions or the social environment (Rudel 2009).

The TGP was designed to build the largest dam on the third longest river in the world. It greatly changed the landscape pattern of the Three Gorges Area. The TGP would create a reservoir area of 1,080 km² by damming the Yangtze River. Then, numerous fertile cropland areas and residential areas would be inundated, and 1.24 million people have been resettled (Liang 2009). Large dams supply many benefits to society but simultaneously impose adverse and often irreversible impacts on the environment (Desiree 2009). It can bring about multiple benefits of flood prevention and control, power generation, and shipping capacity (Zhengli et al. 2004). However, the project will partially induce adverse changes in the eco-environment, land resources, and even on the whole social and economic development in the middle and lower reaches of the river.

To characterize the environmental effects and minimize the adverse influence associated with TGP, environmental impact assessments (EIAs) were undertaken before TGP started (EIA 1996). According to EIA guidelines, the Chinese government formulated a series of relevant policies (Luo and Shen 1994; Tullios 2009) and implemented local ecological protection projects (Wang et al. 2002). Meanwhile, national CWRD implemented to promote local economic growth of the western China and shortened the gap between the western and the eastern China in 2000. Increased investment of infrastructure and presented preferential policies to improve the investment environment, which typically changed artificial surface. The project of “Grain for Green” is a government implemented national ecological protection project that the cropland should be returned to the forests and pastures where the gradient is more than 25°; it influenced cropland change in mountainous area.

In the TGRA, the cropland has been substantially changed as a consequence of anthropogenic activities. As food security is the fundament, a scarce resource, and the key guarantee of sustainable social-economical development, cropland decrease is an issue needs to be focused on the TGRA.

This paper presents quantitative and qualitative analysis of cropland change and land cultivation intensity during the period of TGP implementation, and discusses the driving forces of cropland change.

The study area

The study area of TGRA is located between E106°16′–E111°28′ and N28°56′–N31°44′ (Fig. 1), covered the lower section of the upper Yangtze River, with an area of 58,000 km² and a population of almost 20 million (Meng et al. 2005). It consists of 20 counties or districts of

Chongqing municipalities and Hubei province. Of the region, about 74% is mountainous, 4.3% is plain, and 21.7% is hilly (Peng et al. 2004). The study area is ecologically vulnerable, as great vertical topographic changes make landslides happen frequently (Fourniadis et al. 2007). Due to the monsoon climate, there is obvious seasonality the TGRA. The annual precipitation ranges from 1,000 to 1,200 mm, with 60% of the rainfall occurring between June and September.

TGP was launched officially on December 14, 1994 and last for 15 years. The river was dammed successfully on November 8, 1997. After June 1, 2003, the water level of the dam reached 135 m high (70 m before), the permanent ship-lock started operation, and the first group of power generating units start work. The water level of the reservoir rose to 156 m high in 2006, and 172 m in 2008. The final water level was designed to be 175 m and reached in 2009, when the total storage capacity of the reservoir would be 39.3 billion m³.

The Three Gorges reservoir submerged land area of 632 km², high quality cropland in low altitude and 8 cities were submerged entirely, and other 4 cities were submerged partly. This change reduced the resource loaded capacity of population that was already overloaded before TGP. The submergence of residence led to resettlement on higher locations surrounding the reservoir and increased local population density. To reduce local pressures on resources and environment, and alleviate the conflict between land resources and population growth, the central government decided to resettle about 200,000 immigrants off TGRA to eastern China.

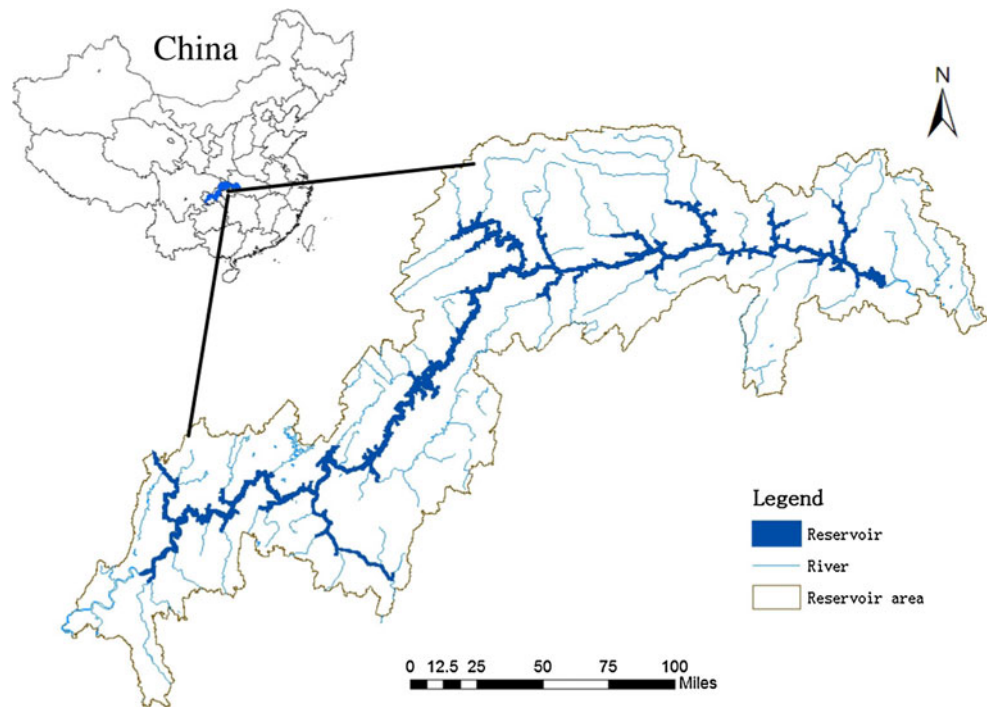
The cultivation of cropland in TGRA has many characteristics: (1) most patches cultivated on high gradient, (2) small patterns and scattered distributions, (3) lack of protection measures for water conservation on slopes for most parts of the cropland, (4) one or two seasonal cultivations throughout the year, (5) low density planting due to the shortage of water and soil nutrients on slopes. These characters make cultivation hard, low productivity and high soil erosion on the croplands.

Data and methodology

Data sources

Remote sensing is widely used in LUCC researches at multi spatial and temporal scales. For cropland mapping at a scale of 1:50,000 in TGRA, we acquired Landsat/CBERS images with a resolution of 30 m for 1992, 2002, SPOT multi/pan images with 10 m resolution for 2002, and SPOT5/ALOS multiple spectral images with 10 m resolution for 2007. For data acquisition capacity or cloud cover,

Fig. 1 Location map of the Three Gorges reservoir area



some images had span in 1 or 2 years. The data selection in 1992, 2002, and 2007 was corresponded to the stage of before the construction of TGP, before inundation of the reservoir to the 135 m high of water level, and before completion of TGP with a water level of 175 m, respectively. For each stage, seasonal images in early spring and summer were selected for the separation of natural vegetation and cropland. Monthly MODIS synthesis data from 2003 to 2009 were processed to estimate the multiple cropping index of cultivation. In addition, to improve the accuracy of the cropland identification and mapping, ancillary data of DEM (digital elevation model) and slope gradient data with a resolution of 10 m, an old land use map at a scale of 1:100,000, crop phenology calendar, and the social-economic census data of TGRA were referenced.

Image pre-processing

Image pre-processing was primarily performed in Erdas9.0 (Leica Geosystems Geospatial Imaging, LLC., Norcross, GA, USA). The procedures include image geo-registration, radiation calibration, atmospheric correction following Berk et al. (1989), and terrain caused spectral correction referenced to Degui and Alan (1998). Geo-registration was delivered on DEM-based ortho-rectification with a processing model of SPOT, TM. Atmospheric correction was conducted using the Atcor 3.0 module, through the Motran 4.0 approach. Terrain correction was performed in Atcor 3.0 to reduce the topographic impact on the spectral reflectance.

Mapping and quantification of land cover

The object-oriented technique is an approach sufficiently using spatial concepts of neighborhood, proximity, or context except for spectral features (Burnett and Blaschke 2003), so as to increase information and improve the accuracy for classification. The classification was composed of segmentation, object creation, decision tree buildup, and classification. It was operated in the eCognition 5.0 software (Trimble Germany GmbH, Munich, Germany). Multiple scale segmentation was prior step to create the spectrally similar objects to extract geometric and spatial information. A suitable segmentation scale for cropland in various regions was useful to avoid the “salt and pepper” phenomenon in classification. The segmentation was based on the unsupervised classification to form multiple scale cluster layers; scales of 10 and 20 were selected to shape different sized cropland clusters. Vector objects were then transformed from the segmented clusters of raster types to retrieve both the geometric and spectral information of the objects. Each object’s spectral information included statistical information of the inner pixels of each band. Each object’s geometry included the features of shape, scale relation, and spatial relation to other objects. These integrated data were input to the database of expert-knowledge-based classification.

The decision tree classifier has the strategies of non-parameter separation and multi-variable decision rules. The advantage of this approach is classifying multiple clusters of feature space for one class, which is not allowed to

operate in the maximum likelihood classification (MLC) approach. Decision tree acquires higher accuracy of classification than MLC in complicated spectral classes, especially for high heterogeneous dryland (Bock et al. 2005). This algorithm was applied for classification and the top-down approach was performed for rule sets creation (Fig. 2). The decision tree buildup was based on two criteria: minimum decision nodes selection for classification; the maximum differences of spectral features considered on the upper hierarchical levels to reduce the omission errors. The multiple rules were made for each node separation to reduce node numbers. The index of VBI, NDVI_on, NDVI_off, slope, and elevation was meaningful to the identification of cropland. The primary idea of cropland retrieval was cropland identification from natural vegetation and bare areas. The NDVI of cropland was lower than natural vegetation during the period of crop shooting up, but higher than bare areas in the crop growth stage.

The accuracy assessment was based on the ground investigation. In situ samples were selected with the method of stratified random sampling according to cropland distribution density based on the 3 by 4 km grid. 217 sample points were then compared with their corresponding points on the cropland map. User's and producers' accuracies statistics for each class were reported (Table 1). The overall accuracy statistic for cropland classification reached 87%.

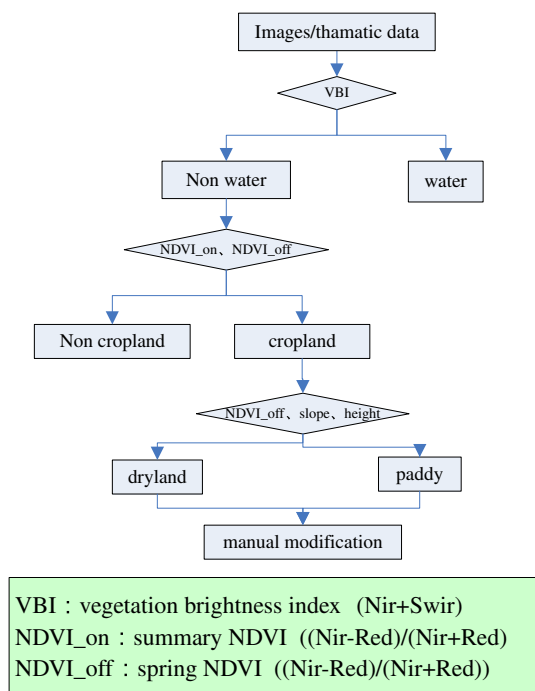


Fig. 2 Framework of decision tree algorithm for cropland classification

Change detection

Despite the wide use of the digital change detection approaches, the method of computer-aided visual interpretation of satellite images (Buttner et al. 2004; Feranec et al. 2007) was applied in the process of updating the 1992 cropland to 2007. This method was applied because spectral distortion caused by steep landforms and heavy haze in the images seriously affected the change detection, and the removal of the impacts of landform and haze was not entirely processed within ATCOR 3.0, a module in Erdas 9.0.

Estimate of land potential productivity

Land production potential (LPP) estimation is based on conversion of plant energy and heat. It is calculated through the correlation analysis of the limiting factors of water, carbon dioxide, and nutrient absorption. The LPP is employed in the assessment of the food production capacity. It represents maximum food production potential under natural conditions. LPP is influenced by the factors of solar radiation, precipitation, air temperature, crop plantation calendar, and soil conditions. The algorithm is as follow, with the normalized score of soil conditions of S_1 , O , S_i being assigned equally according to their content (Table 2).

$$\text{LPP} = \frac{10^8}{C \times 1,000} \times F \times Q \times \frac{n}{365} \times f_{(w)} \times (a \cdot S_1 + b \cdot O + c \cdot S_i) \quad (1)$$

Table 1 Accuracy assessment for cropland mapping

Class	Paddy	Dryland	Others	Total	User accuracy
Paddy	72	0	2	74	97%
Dryland	12	104	8	124	84%
Others	4	15			
Total	88	119			
Producer accuracy (%)	81	87			87

Table 2 Score assignation for soil factor evaluation

Slope gradient	0–6°	6–15°	15–25°	>25°	
Score	0.9	0.7	0.5	0.3	
Soil granule	Clay	Silty clay	Silt	Sandy silt	Sand
Score	1.0	0.9	0.8	0.7	0.5
Soil organic (%)	>2	1.5–2.0	1.0–1.5	0.5–1.0	<0.5
Score	1.00	0.85	0.70	0.65	0.50

$$f_{(w)} = \begin{cases} 1, & r \geq E_0 \\ \frac{r}{E_0}, & r < E_0 \end{cases} \quad (2)$$

LPP: Land production potential, kg/ha; C : dry material heat, the chemical burning energy of 1 g dry matter, the majority of crops average C is 4.25 kcal/g; F : utilization efficiency of sunlight energy (F is depended on crop type, timing of planting, and sun radiation energy. It is a regional parameter. Multi-annual mean of F in TGRA is 2%); Q : annual solar radiation, kcal/cm²; n : frost-free days through 1 year; $f_{(w)}$: ratio of precipitation to evaporation; r : annual precipitation, mm; E_0 : annual evaporation, mm; S_i : assigned score of cropland slope; O : assigned score of soil organic matter content; S_g : assigned score of soil granule; a, b, c : weight value of soil conditions (Weight values are calculated with an approach of Analytic Hierarchy Process, a, b, c are acquired as 0.5, 0.3, 0.2).

Determination of multiple cropping index

Multiple cropping index (MCI) is an indicator of total cultivation intensity in a plot within a year. The equation is as follow:

$$MCI = \frac{S_p}{S_c} \times 100 \quad (3)$$

MCI: multiple cropping index; S_p : planting or sowing areas year round; S_c : cropland areas.

MODIS NDVI of 1 km 16-day maximum value composite (MVC) through a year was employed for the calculation of MCI. The method was based on two assumptions: (1) the NDVI data from a satellite sensor are primarily related to crop growth; (2) clouds and poor atmospheric conditions usually depress NDVI values, forming sudden drops in NDVI, and requiring removal and substitution (Jin et al. 2004). Then, MODIS 1 km NDVI MVC was constructed to produce a high quality NDVI time-series year round. The depression impacts of clouds and poor atmospheric conditions on NDVI values implied that the profiles of NDVI series were not compatible with the gradual process of crop growth. Filtering using a Skewed Gaussian function was performed to make the data approach the upper NDVI envelope, to best fit the NDVI variations during a full crop season through an iteration process (Jonsson and Eklundh 2002).

Results

Spatial-temporal dynamic of cropland pattern

The satellite-based cropland map revealed distinct distribution in TGRA (Fig. 3). The cropland area was

1.42 million hm² in 2007, accounting for 24.6% of the total area of TGRA. The ratio of dryland area to paddy area was 2.1:1. As limited by the slope gradient and elevation, most of the croplands were on the flat region in the western TGRA. Dryland was distributed on the gentle slopes, ridges, and plateau close to the dam. The paddy fields mainly located in alluvial plains and floodplains in the western TGRA, and a small portion on the terraced slopes. Most of the dryland was in a scattered, fragmented pattern in the rough landforms. This led to widespread rural farmers living separately with low incomes due to limitation of traffic inconvenience.

The cropland had declined drastically from 1992 to 2007 (Table 3), with a total decrease of 59,600 hectares, accounting for 4.0% of the total area of cropland. The average annual reduction reached 3,977 hectares. Paddy fields decreased by 11,000 hectares, accounting for 2.4% of the paddy field, and dryland reduced to 48,000 hectares, accounting for 4.8% of the dryland. The rate of dryland loss was faster than paddy field.

Changes of cultivated land from 1992 to 2007 were typically occurred along the Yangtze River and its tributaries in TGRA, which was the region with high population density (Fig. 4). The greatest cropland change occurred in the eastern region along the river before 2002 and in the western region after 2002. The annual average cropland change before 2002 was as 1.5 times the change as that after 2002. This indicates that there was more cropland lost before the reservoir inundation.

Cropland production capacity change

Land production potential (LPP) represents cropland production capacity based on the factors of climatic change, topographic conditions, soil nutrient. The average LPP is 21,780 kg ha⁻¹ a⁻¹ in 2007. A high LPP of 25,500–27,750 kg ha⁻¹ a⁻¹ appeared in the west Zhong County with flat landforms and high sun radiation (Fig. 5). Low LPP of 11,250–14,250 kg ha⁻¹ a⁻¹ appeared in the northeastern steep and low temperature mountains. The average annual grain yield in TGRA was 8,115 kg ha⁻¹ a⁻¹. The actual yield was 37% of LPP in TGRA, indicating a strong potential for food production in TGRA.

The quality of cultivated land determined grain productivity. The decrease in cropland area and changes in its spatial distribution caused land quality changes. Five degrees of cropland production potential were identified for analysis (Fig. 6). Crop production potential from a low of 0–7,500 kg ha⁻¹ to a high of more than 30,000 kg ha⁻¹ accounted for 2.5, 13.5, 33.6, 41.8, and 8.6%, respectively, in 2007. With the loss of 59,700 hectares of cultivated land

Fig. 3 Cropland mapping based on object-oriented approach in TRGA in 2007

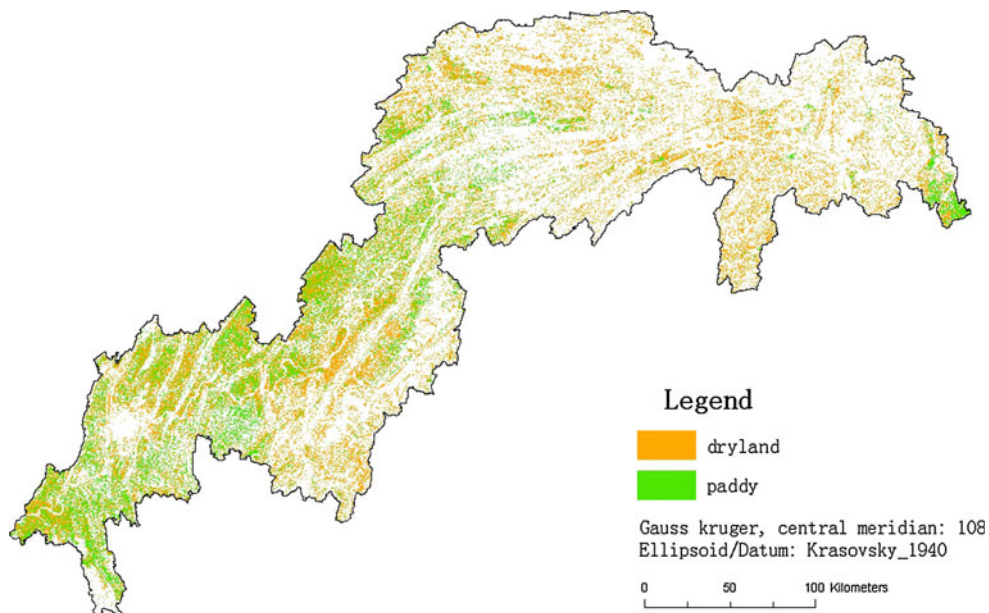
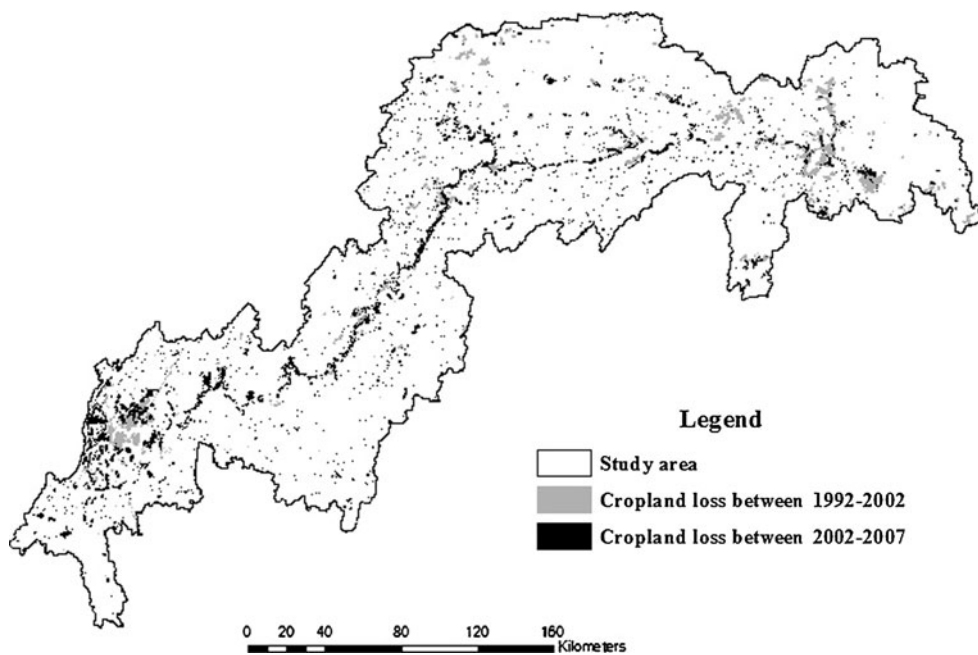


Table 3 Cropland change over the 15-year span in TRGA (ha)

Class	In 1992	In 2002	In 2007	Change 1992–2002	Change 2002–2007
Paddy	468,718	465,640	457,472	−3,078	−8,168
Dryland	1,012,311	981,289	963,902	−31,022	−17,387
Total	1,481,029	1,446,929	1,421,374	−34,100	−25,555
Cultivation index*	0.256	0.250	0.246	−0.006	−0.004

* Cultivation index: ratio of cropland to total area

Fig. 4 Cropland change map in TRGA from 1992 to 2007



between 1992 and 2007, cropland production potential changed from high to low degree accounting for 0.06, 0.20, 0.16, −0.21, and −0.20%, respectively. There was more

loss in high quality cropland than the low quality cropland. Cropland loss in TRGA led to the decline in quality of cultivated land.

Cultivation intensity change

The crop phenology in TGRA allowed for 1–3 season plantings. The convention of cropping in TGRA was basically dominated by the two-season cropping namely, the composition of winter wheat/corn, winter wheat/potato or sweet potato, winter wheat/rice, canola/rice. Some croplands had one-season planting, such as rice or potato according to soil and climate conditions.

Multiple cropping index (MCI) is an artificial factor related to cultivation intensity and food production. Its spatial change is dependent on accumulated air temperature, population density, and economic development level. A high MCI appeared in the western and middle TGRA that surrounding the large cities such as Chongqing and Wanzhou with more frost-free days (Fig. 7). It did not entirely concur with LPP distribution due to human disturbance. MCI changed annually along with the change of agricultural policies and agricultural product price. MCI in TGRA decreased 7.5% from 2003 to 2009. The change of MCI indicates a trend of fluctuating decline (Fig. 8).

Discussion

Driving forces of cropland loss

This study evaluated general cropland patterns, major development trends, and environmental impacts of cropland change in the TGRA during the last 15 years using an integrated method of remote sensing. The spatial conversion matrix of land cover changes with cropland from 1992 to 2007 was presented for analyses of the driving forces

Fig. 5 Cropland productivity in TGRA

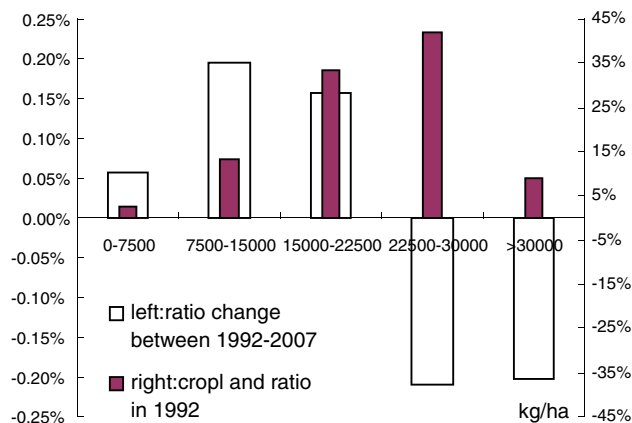
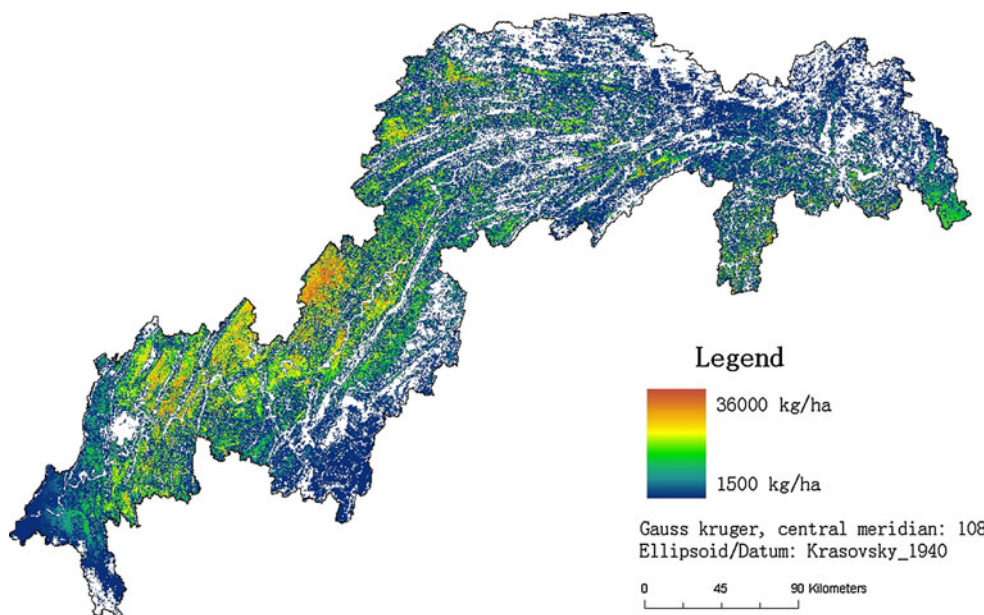


Fig. 6 Cropland production potential change from 1992 to 2007

(Table 4). Human activities significantly drive reduction of arable land in TGRA.

Over the past 15 years, the amount and pattern of cropland in the TGRA changed significantly. Of the changed cropland area, 2,356 hectares of land were converted to cropland, accounting for 3.7%. Meanwhile, 62,010 hectares of cropland were used for non-agricultural purpose, accounting for 96.3% of the changed cropland. The overall trend showed a net reduction in arable land, with an annual cropland decrease on average of 3,977 hectares. This change conflicted to the state Land Management Legislation. The Ministry of Land and Resources implemented the cropland protection regulation against rapid urban expansion and population growth since 1999 to maintain dynamic balance between farmland loss and reclamation. Cropland occupation for non-agricultural use was compensated spatially in other places. Historically,

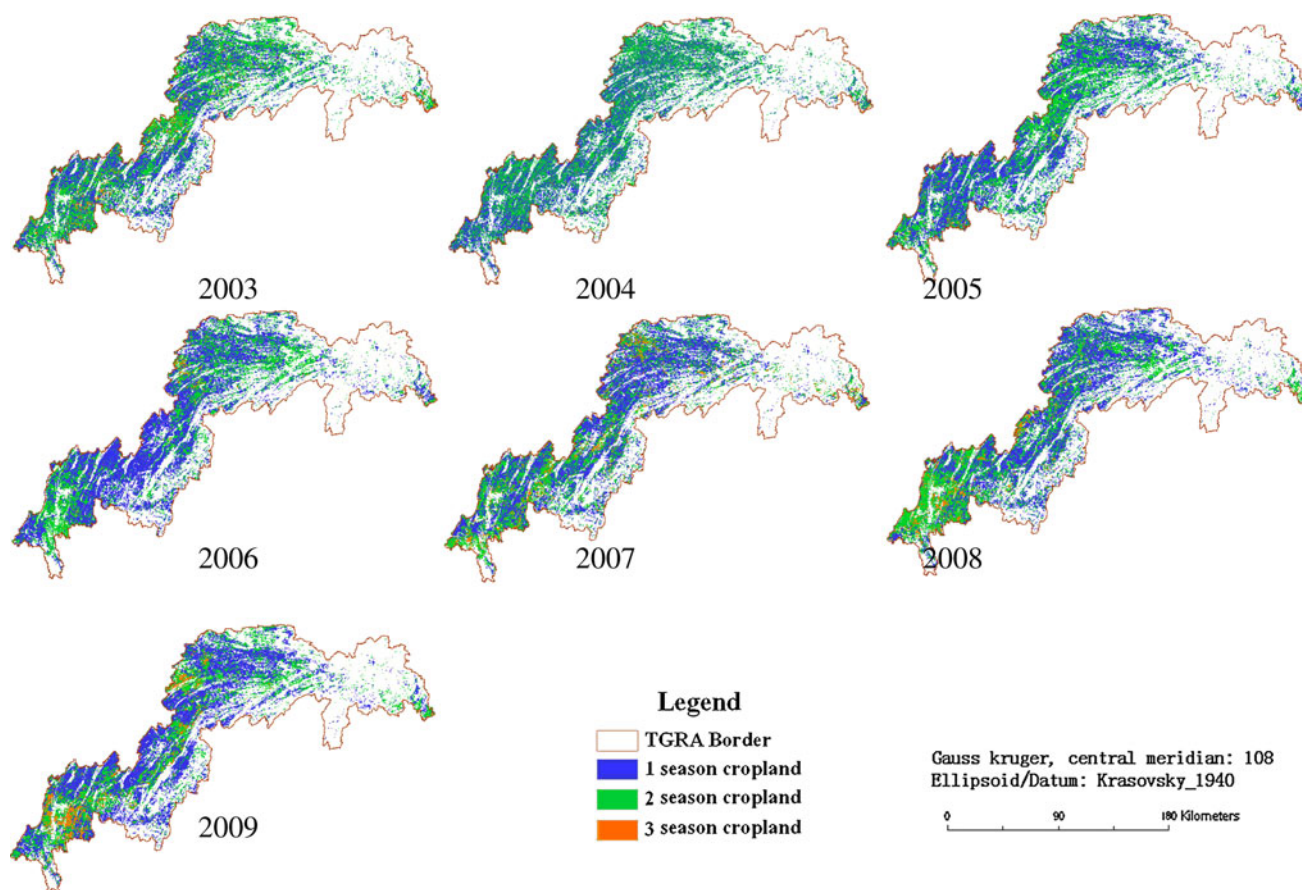


Fig. 7 Multiple cropping index (MCI) between 2003 and 2009 in TGRA

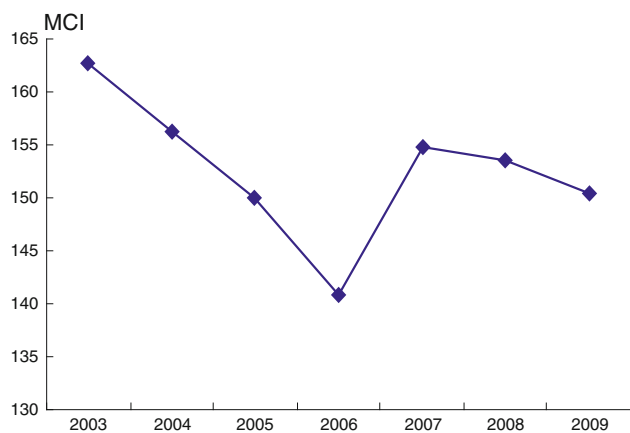


Fig. 8 Multiple cropping index (MCI) change in TGRA since submergence of the reservoir

cropland reclamation reached a peak during 1960s and 1970s when agriculture was the main contributor to economic development (Huang et al. 2006). During this period, most of potential cropland had been reclaimed and led to some cropland distributed on the vulnerable environment. Cropland of slope greater than 25° still accounted for

20% by now. Cropland loss was not able to be compensated spatially and cropland declined in the mountainous TGRA (Fig. 9).

There were 11 classes of land cover that the cropland converted to between 1992 and 2007 in TGRA (Table 4). Most land patches of these classes occupied the cropland in the past 15 years caused a net loss of cropland. The results revealed that occupation of urban construction (buildup and urban vegetation) accounted for 45% of cropland loss. Expansion of natural vegetation cover (evergreen broad leaf, deciduous broad leaf, evergreen needle leaf, deciduous needle leaf, evergreen shrub, deciduous shrub, and grass) accounted for 23% in the loss of cropland. Both the water submergence and orchard cultivation contributed 16% to the loss. The projects such as TGP, CWRD, and EPP topped the list of dominant driving forces for cropland changes (Fig. 10).

TGP construction led to immediate consequences of cropland loss by reservoir inundation and indirect cropland occupation of resident resettlement. Much fertilized cropland and cities submerged located around Yangtze River in low reach in TGRA (Fig. 9). The submerged cities required resettlement and rebuilding. Historically, cities

Table 4 Driving forces and cropland conversion to other land cover in TGRA (ha)

Driving forces	Classes converted with cropland	Cropland increase	Cropland decrease	Cropland net change	Proportion (%)
EPP	Evergreen broad leaf	87	396	-309	1
	Deciduous broad leaf	31	1,548	-1,517	3
	Evergreen needle leaf	302	862	-559	1
	Deciduous needle leaf	2	356	-354	1
	Evergreen shrub	553	3,949	-3,396	6
	Deciduous shrub	19	1,232	-1,213	2
	Grass	885	5,779	-4,894	8
TGP, CRWD	Buildup	10	26,987	-26,977	45
	Urban vegetation	1	1,066	-1,066	2
TGP	Orchard	335	9,944	-9,609	16
	Water	132	9,891	-9,759	16
	Total change	2,356	62,010	-59,654	100
	Ratio of change (%)	3.7	96.3		

“Cropland increase” represents cropland converted from other land cover; “cropland decrease” represents cropland converted to other land cover; “cropland net change” represents the total area change between cropland and other land cover

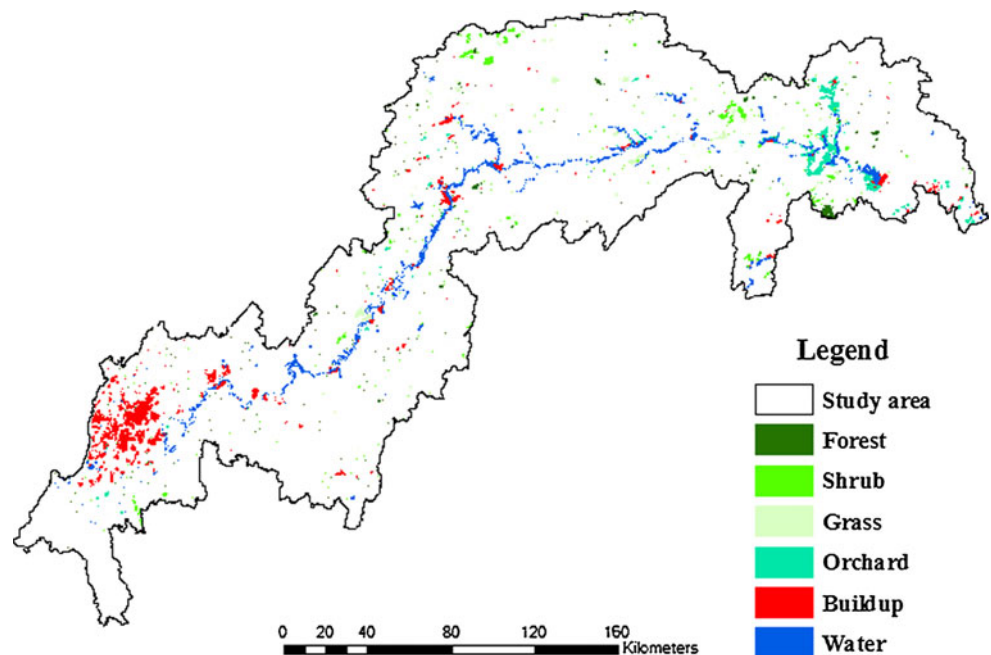
development and spatial expansion along river were limited by the terrain, new layout cities were distributed on flat and wide valley, most of which were occupied by cropland before. With a lower urban buildup density, immigrated urban extents were larger than previous cities. Urban resettlement gave an opportunity to adjust urban structure and to improve its function, but these change consumed much more cropland in TGRA.

TGP also influenced local agricultural policy for the promotion of orchard plantation. Cropland of high productivity submerged by the reservoir at low altitude

typically impacted agriculture development and farmer’s income. To minimize the economic loss of cropland production, the local policy of planting structures regulation encouraged the development of orchard plantations instead partially of cropland to increase the farmer’s income. Much cropland, especially low quality cropland distributed on slopes gradients of more than 25°, substituted by orchard field.

CWRD implementation drove local economy and urban development. It increased infrastructure investment and supplied preferential policies to promote local economy.

Fig. 9 Land cover conversion from cropland in TGRA between 1992 and 2007



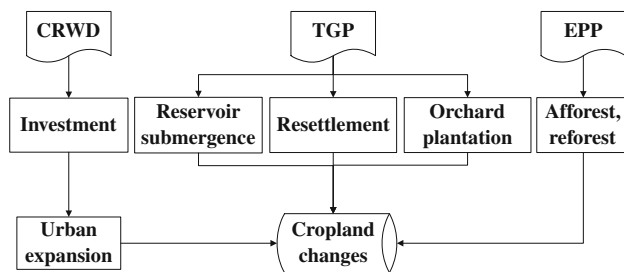


Fig. 10 Driving forces impacting cropland changes in TGRA

The preferential policies covered industrial tax, land-holding, mining, and overseas investment, etc., that attracted remarkable investment in TGRA from the eastern China. There were many industrial and economic development zones appeared surrounding the cities in the western TGRA. According to annual official local socio-economic statistics, the GDP ratio of agriculture, industry, and services changed from 35:38:27 in 1992 to 14:50:36 in 2007. GDP portion of industry and services increased. Meanwhile, The Chongqing District (most in the western TGRA), which was chosen as an economy polar in the strategic decision of center government to accelerate development of the western China and priority management of TGP, was established in 1998. It promoted urbanization of the western TGRA. Urban land, particularly in the western reservoir area of Chongqing municipality, expanded rapidly and occupied much cropland (Fig. 9). Urban expansion absorbed a large amount of farmers. But the cropland loss as a consequence of urban expansion was less than that once owned by farmers who immigrated to cities. This alleviated cropland pressure in rural areas, which was favorable to food supply and stable life of the rural population.

There were series of EPP speeded up the arable land decrease. The vegetation converted from cropland distributed in the mountainous and marginal area that was primarily affected by EPP (Fig. 9). The Key Measures of Soil and Water Conservation Program had been implemented since 1989 in the Yangtze River upstream. What's more, the "Grain for Green" Project had been implemented since 2002. The croplands with slope gradient greater than 25° were abandoned for revegetation to reduce soil erosion. Other ecological projects such as Green Belt Construction in 2004–2010 took action to improve the landscape quality surrounding the TGRA. The EPP implementations accelerated the abandonment of cropland with low productivity and high soil erosion in TGRA.

Effect of EPP was not very well due to high population density and low benefit of land compensation. This was the reason of 20% of cropland on slope gradients of more than 25° still existed. The fragile ecological environment in TGRA and the security requirement of Three Gorges Dam

cannot tolerate intensive land reclamation. The project of "Grain for Green" is needed to be continued for steep cropland that contributed to soil erosion. However, it inevitably decreases the cropland and strengthens the pressure on rural food supply.

Driving forces of cropland quality degradation

Overlapping the cropland productivity map (Fig. 5) and land cover conversion map (Fig. 9), among high quality cropland loss (potential yield >22,500 kg/ha), buildup and water cover account for 53 and 22%, respectively. This was primarily caused by urban sprawl, resettlement, and the reservoir submergence, which occupied mainly the low-altitude, gentle slopes with high heat and fertile conditions. Of the loss in low quality cropland (potential yield <15,000 kg/ha), the vegetation and orchard occupation account for 67 and 26%, respectively. The "Grain for Green" project implementation led to cropland loss on steep slopes that previously suffered severe soil erosion and soil nutrient loss. Although this project decreased some low quality cropland, but it accounted for a small part of cropland loss in TGRA and resulted in the average cropland productivity being degraded.

Driving forces of cultivation intensity decrease

The Chinese economy was rapidly developing during the implementation of the TGP. The GDP grew steadily with an annual rate of 9–11%. Urban expansion and development had created dynamic labor markets, driven the spare labor force from agriculture to other industries and from rural to urban areas (Lambin and Meyfroidt 2010; Ignacio 2011). Although the government implemented preferential agricultural policies to protect farmers' benefits, the rural labors were still pouring into cities (Yardley 2004). The annual planting area of cropland in TGRA continuously decreased since 2003. An agricultural tax free ordinance was issued in 2006 to increase rural investment and provide policy support for the improvement of farmers' incomes and living conditions. As a result, MCI increased rapidly in 2007. However, it was not long before MCI step on the way of decrease. With poor cropping terrain, traffic inconvenience, high cost of planting, and low agricultural incomes in TGRA, it was hard for farmers to increase MCI to compensate the food losses caused by cropland decline. This indicates that agriculture was an only fundamental source of incomes, the life improvement of farmers required a variety of business approaches, as the income gap between urban residents and rural farmers had enlarged in recent years. The farmers inclined to find temporary jobs in the city for a higher income. To increase MCI and improve local food supply, the improvement of production

conditions, increases in agricultural product prices, and government subsidies are needed.

Conclusions and outlook

The results of this study showed that the human activities caused a significant loss of cropland in the TGRA from 1992 to 2007. The total area of cropland decreased by 4%. The loss of cropland has not been compensated by reclamation due to the limited land resources. The high quality cropland accounts for 61% in the cropland loss. The cropland decline has speeded up the rapid reduction in land productivity. Cultivation intensity decreased by 7.5% in TGRA from 2003 to 2009, which showed a trend of fluctuating decline.

The reduction in arable land is primarily due to urban sprawl, ecological projects, orchard industry development, and reservoir inundation. Urban expansion results in 45% of the reduction in arable land. Urban sprawl and submergence of the reservoir have covered high quality cropland, and thus played an important role in cropland productivity decline. The enlarged income difference between urban and rural areas decreased cultivation intensity despite the tax reduction and subsidies of the agricultural policies issued.

With the “Grain for Green” Project implemented and the urbanization development promoted in the coming years, areas of cropland will keep reducing. Meanwhile, referring to the security of the reservoir, TGRA also faces high environmental pressure. Urbanization is probably an effective way of reducing the pressures of the rural land resources and ecological environment. It is suggested that rural labors require to be resettled gradually to cities through favorable policies, such as employment changes and skill training.

Acknowledgments This research was funded by the project of “ecological and environment dynamic monitoring with remote sensing in TGRA” from the Three Gorges Project Construction Committee of the State Council(No: SX[2002]-004) and the “Strategic Priority Research Program—Climate Change: Carbon Budget and Related Issues” of the Chinese Academy of Sciences (No. XDA05050109); the Knowledge Innovation Project of the Chinese Academy of Sciences: Key project monitoring and assessment of ecological environment effects (No:KZCX1-YW-08).

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